Final Technical Report for: **Global MHD Simulation of Mesoscale Structures at the Magnetospheric Boundary**

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Administrative Matter

Due to the reorganization of NASA grants office from Head Quarter to the Goddard Space Flight center, this grant is a continuation of the NAGW-4541 grant. In order to give a complete review of the funded effort, this final report covers also the research under the original NAGW-4541 grant.

Research Summary

The research carried out for this protocol was focused on the study of mesoscales structures at the magnetospheric boudary. We investigated three areas:

- the structure of the magnetospheric boundary for steady solar wind conditons
- the dynamics of the dayside magnetosperic boundary
- the dynamics of the distant tail magnetospheric boundary.

Our approach was to use high resolution three-dimensional global magnetohydrodynamic (MHD) simulations of the interaction of the solar wind with the Earth's magnetosphere. We first considered simple variations of the interplanetary conditions to obtain generic cases that helped us in establishing the basic cause and effect relationships for steady solar wind conditions. Subsequently, we used actual solar wind plasma and magnetic field parameters measured by an upstream spacecraft as input to the simulations and compared the simulation results with sequences of events observed by another or several other spacecraft located downstream the bow shock. In particular we compared results with observations made when spacecraft crossed the magnetospheric boundary.

Magnetospheric boundary for steady solar wind conditions

We started our research effort by modeling of the solar wind/magnetosphere interaction for steady solar wind conditions by carrying out a series of three-dimensional global magneto-hydrodynamics (MHD) simulations using a set of predetermined solar wind parameters as input to the code. These runs cover three regimes of constant dynamic pressure:

regime	density (cm^{-3})	velocity (km/s)	thermal pressure (pPa)
low:	5	300	3.45
medium:	7.3	420	5.04
high:	10	650	13.81

For each of these three regimes we simulated three periods of 40 minutes each, using different directions of the interplanetary magnetic field (IMF):

south :	B_x=0 nT	B_y=0 nT	B_z=-5 nT
dusk:	B_x=0 nT	B_y=5 nT	B_z=0 nT
north:	B_x=0 nT	B_y=0 nT	B_z=5nT

In addition, the nine sets of steady solar wind conditions defined above were run for four different tilt angles of the Earth's magnetic field dipole: minimum tilt (0°), maximum tilt (35°), average winter tilt (Sun -22.90°, Dusk -00.43°) and average summer tilt (Sun 23.61°, Dusk 00.68°). These 36 data sets were used as a database for our study of the magnetospheric boundary during periods of steady solar wind conditions.

We investigated the geometrical properties and the topology of the magnetic and electric fields at the magnetospheric boundary for the different solar wind regimes and orientations considered. In particular, we investigated magnetic reconnection occurring at the dayside boundary. Results indicated that merging sites are consistent with patterns proposed for antiparallel merging at the dayside magnetopause [*Berchem et al.*, 1995a]. Another area of study of the investigation was the displacement of the cusp region as a function of the solar wind dynamic pressure, IMF direction and magnetic field dipole tilt. Several case studies were used to establish a series of criteria in to permit a routine identification of the response of the cusps to changes in solar wind conditions [*Escoubet et al.*, 1997]. In particular, we examined the variation of the cusp locations as a function of the interplanetary magnetic field (IMF) for two different levels of solar wind dynamic pressure (0.7 and 7 nPa). Although the location of the external boundaries of the cusps vary greatly with changes in the dynamic pressure of the solar wind, results from the simulations indicate that the invariant latitudes of the equatorial and polar boundaries of the cusps are not significantly affected. The most noticeable change was found for southward IMF, for which the invariant latitudes of the equatorward boundaries are found to be at lower latitudes for high solar wind dynamic pressure. The latitudinal locations of the cusps have a much stronger dependence on the value of the IMF Bz component than on the solar wind dynamic pressure. Results for the equatorward boundaries are in very good agreement with those from statistical studies. The locations of the poleward boundaries found for northward IMF, however, differ significantly from observational values and are more consistent with the locations extrapolated from velocity-dispersed precipitation of ions [*Berchem*, 1997; *Berchem et al.*, 1997a].

Dynamics of the dayside magnetosperic boundary

We studied the dynamics of the dayside magnetospheric boundary for periods of very disturbed conditions by simulating the interaction of an interplanetary shock with Earth's magnetosphere that occurred on August 27, 1978. This event was first observed by ISEE 3 at L1 and about 25 minutes later by ISEE 1 and 2, located at about 10 R_E in the subsolar region. The ISEE 1 and 2 spacecraft measured a strong compression pulse followed by a very rapid earthward motion (~ 200 km/s) of the magnetopause. Using the plasma parameters and magnetic field measured by ISEE 3 as input to our high resolution global MHD code, we investigated the response of the magnetospheric boundary to the disturbance. Comparison of the ISEE 1 and 2 measurements with simulated time series at the spacecraft locations revealed excellent agreement between the simulation results and the observations. This agreement provided the basis for the investigation of the mesoscale structure of the boundary before and after the interaction, as well as the global geometry and dynamics of the magnetospheric boundary during the event. In particular the simulation was able to show that the short incursion into the solar wind observed by one of the spacecraft (ISEE-2) during the event resulted from a change in the global curvature of the magnetopause rather than a change in the local topology of the boundary. These results were reported at the AGU spring meeting [*Berchem et al.*, 1995c] and the IUGG Meeting in Boulder, Colorado [*Berchem et al.*, 1995b].

Another simulation study of the dynamics of the dayside magnetospheric boundary was carried out using data from the GEOTAIL and WIND spacecraft. The study addressses the complexity of the magnetic field topology and convection patterns that can occur at the dayside magnetospheric boundary for periods of northward IMF with strong B_X and B_Y components and large plasma density fluctuations. This study is based on events observed on December 27, 1994, while Geotail was skimming the dayside magnetopause and the Wind spacecraft was monitoring the solar wind. Contour plots of the plasma density obtained at different times in the simulation show the tailward convection of the gusts of plasma in the magnetosheath, which appears as a large amplitude wave propagating on the surface of the magnetospheric boundary [*Berchem et al.*, 1996a]. The simulation also shows that the draping of the magnetosheath field over the afternoon and dusk sectors accounts for the negative X component of the magnetic field observed by Geotail. Something less expected though, is the warping of the field lines in the dusk magnetosheath because of the X component of the IMF. An immediate consequence of the large reversal of the field is to create a region of low magnetic field and high density, i.e. high beta plasma, in the dusk flank of the magnetosheath. Considering that those field lines are open, such a configuration can explain the presence of a relatively steady boundary layer populated by a mixture of magnetospheric and solar wind plasmas [*Berchem et al.*, 1996b, c]. The results also show that a field line that is reconnected on the dawnside, convects over the entire dayside boundary because of the field tension and the tailward motion of its open end in the dusk flank of the magnetosheath. An interesting consequence of this convective transport of plasma from dawn to dusk, is that it implies sunward flows in the dawn and prenoon regions of the boundary layer [*Berchem et al.*, 1998a].

Dynamics of the distant tail magnetospheric boundary

We also used comparison between observations and simulation to study the dynamic and topological aspects of mesoscale structures observed when crossing the tail magnetospheric boundary. This study was based on an investigation of the evolution of the distant tail boundary at 200 R_E from the Earth. The events used in that study were observed on July 7, 1993, when the direction of the IMF was predominantly northward and marked by a slow rotation of its clock angle component. Results from the simulation show that the asymmetric stresses imposed by the draping of magnetosheath field lines and the unbending of the newly reconnected IMF considerably alter the shape of the distant tail as the solar wind discontinuities convect downstream of the Earth. As a result, the cross section of the distant tail is considerably flattened in the direction perpendicular to the IMF clock angle, the direction of the neutral sheet following that of the IMF. The simulation also reveals that the combined action of magnetic reconnection and the slow rotation of the clock angle component of the IMF lead to a braiding of the distant tail magnetic field lines along the axis of the tail with the plane of the braid lying in the direction of the IMF. Such a twisted configuration explains the mesoscale structure observed at the boundary and the rapid traversal of the tail lobes. Another important feature also revealed by the simulation is that unconnected field lines resulting from the reconnection of lobe field lines with solar wind field lines at the high-latitude magnetopause cross the 200 R_E plane in a region that one might expect to be filled by open field lines from the lobes. Such a configuration seems to be the counterpart of the magnetospheric asymmetries associated with the Y-component of a southward directed IMF. When this occurs, flux is added preferentially to the dusk side of the northern lobe and to the dawn side of the southern lobe for IMF $B_Y < 0$. Results from the simulation suggest that for a northward IMF with $B_Y < 0$, flux is removed preferentially from the dawn side of the northern lobe and from the dusk side of the southern lobe [*Berchem et al.*, 1997b, c; *Raeder et al.*, 1997; *Berchem et al.*, 1998b].

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Patents and Inventions

None